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ORIGINAL ARTICLE

Quantitative evaluation of the effect of prohibiting grazing policy on grassland desertification reversal in northern China

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Abstract In northern China, the recent eco-environment protective policies played a very important role in the ecological environment protection and rehabilitation. To better understand the quantitative effect of the prohibiting grazing policy on grassland desertification reversal process, in this paper, Yanchi County was selected as a case study to conduct a quantitative research on the effect of prohibiting grazing policy. System dynamics research method was used in this study, also both natural factors and human factors which importantly related to desertification had been considered in the index system of the system dynamics method. According to the different grazing prohibition degree from 0 to 100 %, model was set up to simulate the grassland desertification degree. The results showed that grassland desertification degree decreased with the increase of the grazing prohibition degree. When the grazing prohibition degree was 30 %, grassland desertification began to reverse, and when the grazing prohibition degree was 40 %, the trend of grassland desertification reversal was steady, and the speed of desertification reversal was the same when the grazing prohibition degree changes from 40 to 100 %. Therefore, the full prohibiting grazing policy in Yanchi County currently is not necessary at all. These results could be very useful for the applying of prohibiting grazing policy in Yanchi County and other regions with the similar eco-environment protective policies.

Keywords Prohibiting grazing policy · Grassland · Desertification reversal · Agro-pastoral ecotone · Northern China

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Introduction

Desertification, a kind of land degradation, is a very important issue in the field of eco-environment and social economics, and which has been paid more and more attention during recent years (Verstraetel et al. 2009; Zuo et al. 2009a). More than 110 countries are confronted with desertification in the world, involving 70 % of global agro-plough and almost a billion people, and which caused worldwide poverty and immigrant (Arrow et al. 1995; Abahussaina et al. 2002; Portnor and Safriel 2004). Desertification is the most serious problem of eco-environment in northern China. Although the prevention and cure of desertification in China have obtained great achievement during the past 60 years, the problems of "rehabilitation partially, deterioration on the whole" are still relevant today (Wang et al. 2004).

In northern China, desertification is usually caused by both natural factors and human factors (Zhou et al. 2010; Dong et al. 2010), which is defined as degradation of land characterized by the action of blowing sand. It is typically indicated by the presence of various aeolian landforms, such as sand dunes (Zhu and Liu 1984). Zhu et al. (1989) definitely indicated that desertification caused by the inharmonic of excessive human activities and resource environment in arid, semi-arid and part of semi-humid regions. Desertification mainly occurs in the fragile eco-environmental regions where the human activities refer to agro-pastoral activities dominated or interfered by temporal policies. In the desertification rapid development period of history, such as in 1858 Qing dynasty, the policy of "Immigrate to the Boundary and Explore Barren Lands" was implemented, and which resulted in a sharp increase of farmland area in the regions unsuitable for cultivation, becoming a potential threat to the desertification development of today. And after 1950s, because of the sharp increase in population and the rapid development of agro-pastoral industry, especially inspirited by the policies of "Great Leap Forward" and "Take Grain as the Key Link", there was a large area of grassland and woodland transformed into cultivated land, and which also accelerated the development of desertification (Wang 2003).

Recently, to restrain the desertification development, the country and local governments implemented a series of eco-environment protective policies, such as "Grain for Green Project" (that means return farmland to woodland or grassland) and "Prohibiting Grazing Policy", which have gained some effects in the reversal of desertification, especially in agro-pastoral ecotone of northern China (Gerile 2004; Lv et al. 2005; Zhu 2006; Ma et al. 2006; Li et al. 2007; Zhao et al. 2008; Zuo et al. 2009b; Jia et al. 2009; Ao et al. 2010). The desertification area in agro-pastoral ecotone of northern China decreased at the speed of 1283 km^2 per year according to the published results of National Forestry Bureau in 2005 (Zhu 2006), and which meaning that the policies have taken effects in controlling the desertification development. Many researches also indicated that ecological environment protective policies play an important role in the rehabilitation process of desertification (Bao et al. 2008; Han et al. 2004; Zhao et al. 2009; Wang et al. 2009; Zhang et al. 2010; Li et al. 2010). However, there was a lack studies on quantitative evaluation on the effects of eco-environment protective policies. It will be a new endeavor in making quantitative standards and scientific evaluation of that. In this paper, taking Yanchi County located in agro-pastoral ecotone of northern China as a case study, a quantitative evaluation on the effect of prohibiting grazing policy on grassland desertification reversal process has been conducted based on the system dynamics model.

Materials and methods

Study area

Yanchi County (37°4′N–38°10′N, 106°30′E–107°47′E; elevation 1,295–1,951 m), covering an area of 6,743 km^2, is located in the east of Ningxia Hui Autonomous Region in northern China, and belongs to the middle temperate zone continental monsoon climate (Chen and Duan 2009), where the average annual precipitation is 290 mm and the mean annual temperature is 8.2 °C, and the main plants are dry steppe and desert steppe. The animal husbandry has always been the main industry of Yanchi County, and in recent decade the proportion of agriculture increased year by year.

In Yanchi County, farmland, grassland and sand dunes are alternate distributed, and the landscape characteristics is extremely representative in the agro-pastoral ecotone in northern China, and the remarkable feature of desertification is that the landscape change from grassland and farmland to desert. Grassland desertification was severe in Yanchi County because of the natural condition and some human activities, including over-grazing, over-cropping, and over-cutting. The obvious desertification reversal mainly happened in recent decade after 2002 when the eco-environment protective policies were applied there.

System dynamics model

In this paper, System Dynamics is used to analysis the desertification process and simulate the desertification reversal process under the prohibiting grazing policy. System Dynamics has been proved to be a good method of understanding the complex dynamic behavior, which was established by an American scientist named Forrester in the 1950s. This model can simulate system structure, function and behavior relationship between the dynamic changes effectively by combining feedback control principle and logical analysis of cause and effect, and which applies to simulate the complicated system with mutually dependent elements, and many of the elements have obvious nonlinear relationship. Given these characteristics, this method was originally applied to the socio-economic systems, and the more influential application of which is the establishment of System Dynamics Globe Model. After the book "The Limits to Growth" published, this method caused a strong repercussion in the worldwide research spectrum of environmental science and technology, and then has been gradually broadened. At present, System Dynamics methods have been widely used in ecology, social science, economics and other research fields (Saysel et al. 2002; Guneralp and Barlas 2003; Costanza and Voinov 2001). In this paper, Stella software developed by ISEE System Corporation is used as a platform of the model.

Figure 1 is the flow chart of the desertification system dynamics analysis model set up. Because the grassland desertification was associated with the social–economic–environment feedback system, both of the grassland system and economic system in Yanchi County were selected as

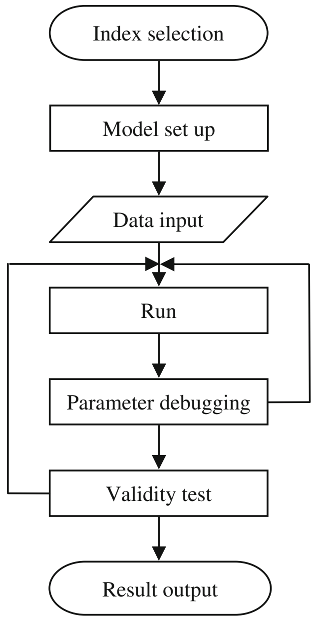


Fig. 1 Flow chart of the desertification system dynamics analysis model set up

the analysis object in this model. This paper established the index system of the system dynamics by analyzing the natural and social influence factors in the process of desertification and its rehabilitation. According to the mechanism of the process of desertification and its rehabilitation, combined with the practical situation of grassland desertification in Yanchi County development, the theoretical model was constructed. Input the required data and run the model, and then test the validation. If possible, output the operation results; if not, adjust the model parameters or the model and then continue to run the model until the error between the simulation and the actual value is within the permissible range. Finally, analyze the simulation results. The process of parameters debugging is decision-making process, which is also an optional process. The model validation must be carried out after establishing the model, because the validation is to verify the similarity between the structural model and real system. The model can only be available through the validation, including visual inspection, operation inspection, history inspection, sensitivity inspection and so on.

Index selection

In this model, the natural factors and human factors are combined by normalization method, and the effects on desertification reversal caused by eco-environment protective policies are taken into consideration as the important factors. The selected indicators included natural factors (the mean annual precipitation, the mean annual air temperature, and the annual strong wind days) as well as the human factors (amount of population, amount of livestock, area of arable land, etc.). These factors were compared with the trend of desertification.

Figure 2 shows the standardization of the data about desertification area and the natural and human factors affecting the desertification, and the results of tendency analysis indicated that in the past 50 years the main trend of climate change have no obvious correspondence with the trend of desertification area. For example, the number of strong wind days is the most apparent, which significantly decreased, then kept stable and rose slightly in recent years, while desertification area in the 1970–1980s increased, then gradually reduced and continued to show a decreasing trend in recent 10 years. Obviously, the number of strong wind days is not the key natural factor playing a major role in the desertification, so it is not considered in model. The fluctuations of the mean annual air temperature and mean annual precipitation are greater, and the mean annual air temperature exhibited a significant increasing trend, yet precipitation had no obvious trend. Both of them greatly affected the grassland yields and determined the development of desertification as well as other factors. Therefore, mean annual air temperature and mean annual precipitation were considered the main natural factors in the model.

Comparing the desertification trend with the trend of major human factors (Fig. 2), it was shown that there was a little difference between the years before 1980 and after 1995. Before 1980s, desertification area had a clear upward trend; also the rural population and the arable land area showed an increasing trend, especially the rural population increased significantly, and the trend of amount of livestock population fluctuated with a slight downward trend. After 1995, desertification area gradually decreased within a small range, and the rural population maintained at a certain level without any change even after two transfers of the rural population to urban population. The number of livestock was in a clear downward trend, and then rose sharply in a significant trend after 2002. As for the arable land after 1995, though the area decreased at 2001, and then increased, the overall trend was still downtrend slightly.

Model constructions

Considering these indexes and the ecosystem structure, Stella software was used to set up the model of desertification and its rehabilitation in Yanchi Country. The model included two mutually restrictive sub-models of population and natural resources. The amount of population determined the consumption of resources, and the remaining resources would influence the population growth rate or

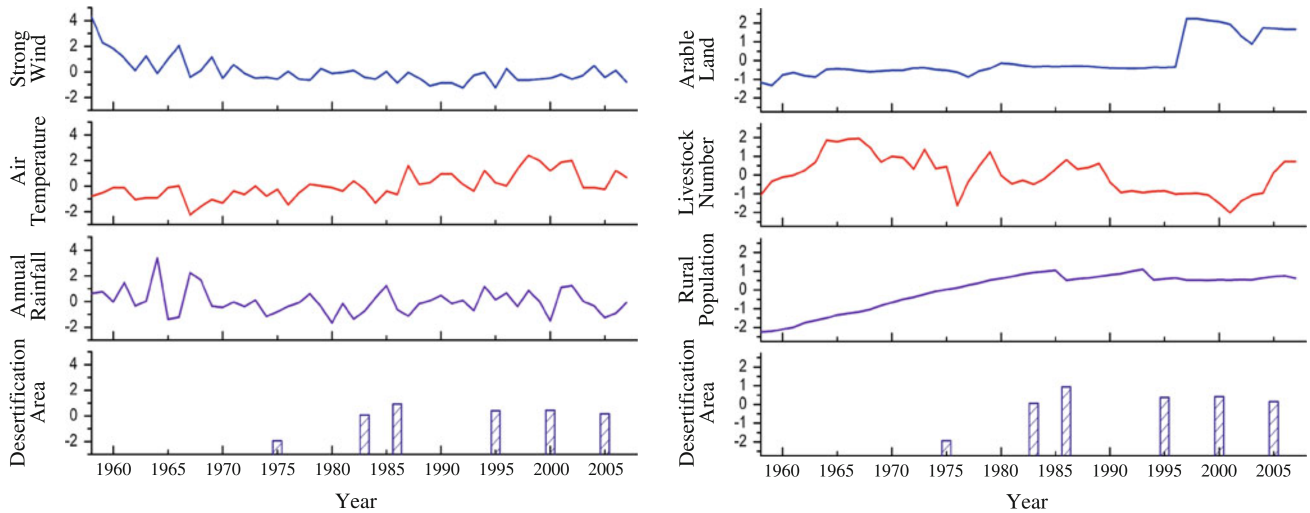


Fig. 2 Development trend of desertification area contrasting with the natural and human factor change

urbanization rate. Therefore, there is a negative feedback between them. The population sub-model is mainly determined by the "stock", "flow" and "flow rate". "Stock" is the rural population and urban population. "Flow" means the increasing annual rural population, urban population, and the annual population from rural to urban. "Flow rate" is defined as the natural population growth rate and population transfer rate. Natural resource sub-model is mainly determined by the amount of required grass of livestock and the total annual grassland yield, and interaction between determined the transfer relationship between desertification area and grassland area. Among of them, the grassland yield is mainly determined by the forage yield per unit area influenced by the mean annual precipitation and mean annual air temperature, grassland area, and desertification area. The amount of grass which livestock require is determined by the number of livestock and the amount of grass required by per livestock, and which are mainly determined by the population. Meanwhile, the change of cultivated land area will also impact on the desertification area. The process of the model constructions is shown in Fig. 3.

Model running and validity test

The desertification area of Yanchi County from 1983 to 2002 had been simulated based on the system dynamics model. The simulation results were proved feasible through the effective tests (including visual inspection, operational testing, historical testing, and sensitivity analysis). And then, the data from 1983 to 2007 were entered and the simulation results were output. The comparative analysis on the trend of desertification area of simulation results and actual are shown in Fig. 4.

There is great difference of 63,100 hm^2 between the simulation and the actual values of the desertification area in 2005 with the relative difference of 36.9 %. Yet, before 2005, the simulation and the actual value of desertification area are so close that the ranges are within the allowable error. On the basis of the published references and investigation, it can be inferred that the difference had much to do with the implementation of various ecological environment protective policies in recent years, especially the prohibiting grazing policy. The aim of the prohibiting grazing policy is to control the forage consumption of livestock. The grazing behaviors (such as grazing time, grazing routes and places, and livestock amount) changed greatly before and after the implementation of the prohibiting grazing policy, and which consequently caused the significant decrease of the daily livestock grazing.

Results and discussion

According to the process of the above model, the major factor affecting the process of grassland desertification and its rehabilitation is the conflict between the grassland yield and the requiring grass forage yield. In some cases, though the grassland yield could be improved through some rational management, it is mainly determined by the natural objective conditions, such as rainfall, temperature, soil and so on. The required grass forage yield is determined by people, which is mainly controlled by the amount of livestock. The positive correlation between them means that the greater is livestock amount, the more grass forage yield would be required. Meanwhile, the decrease of the grassland due to being occupied by cultivated land, especially

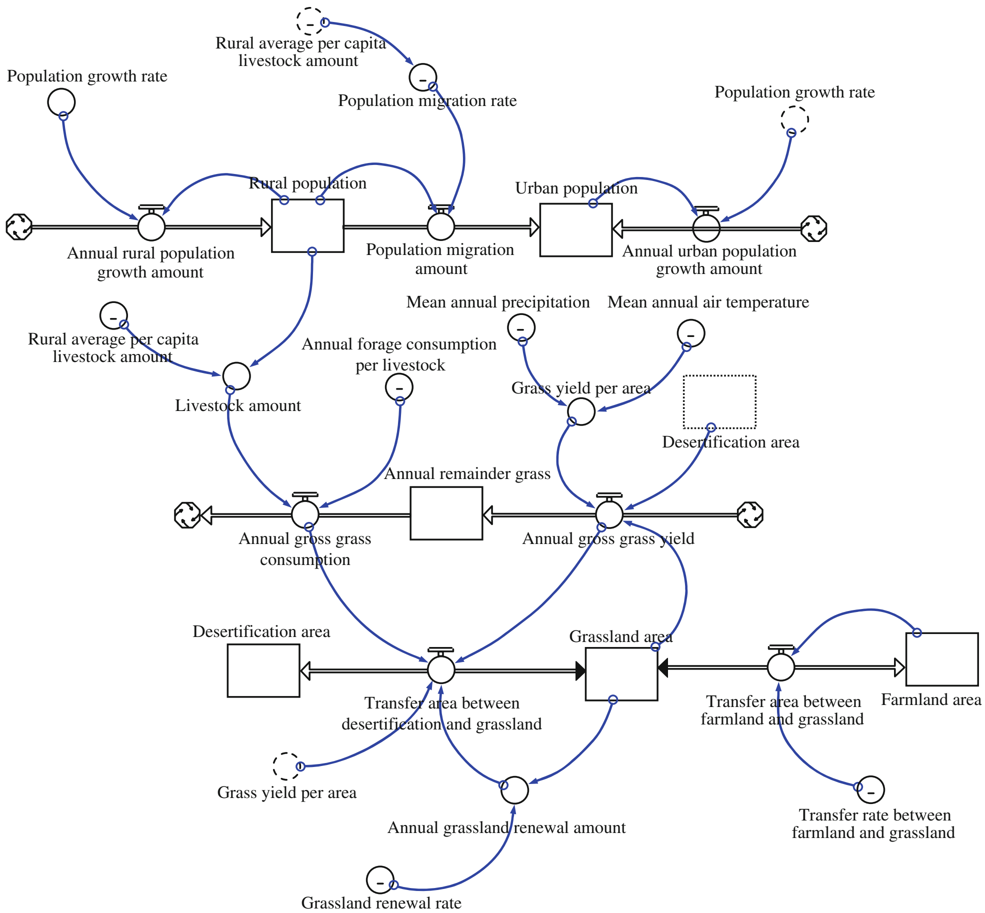
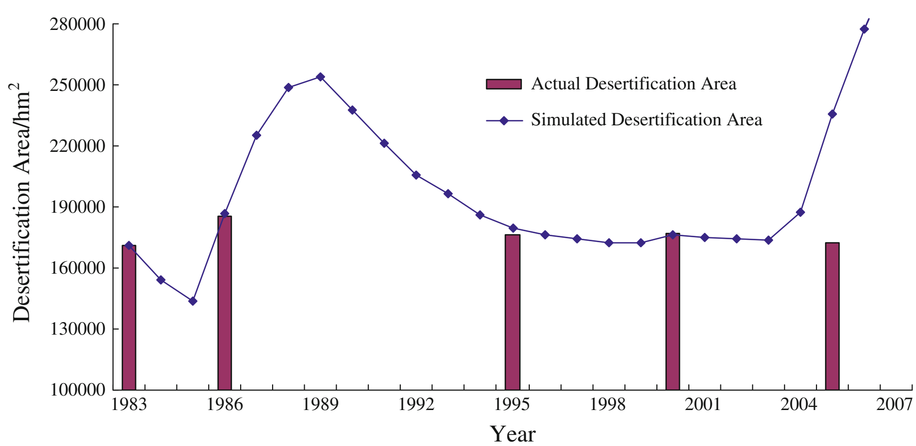


Fig. 3 The system structure flow chart of desertification system dynamics model

Fig. 4 Contrast of the model simulated desertification area trend and actual desertification area



by the new reclaimed cultivated land and abandoned land, affected the grassland area, grassland yields to some extent, and thereby the desertification area. This paper focuses on the quantitative effect of eco-environment protective policies on desertification and its rehabilitation process by changing the different degree of implementation of prohibiting grazing policy.

Reversal threshold of desertification and its rehabilitation

The implementation extent of prohibiting grazing policy is defined as “Grazing Prohibition Degree (GPD)”, which is directly corresponding to the amount of fresh grass that livestock graze daily. When a value of GPD is 0, meaning

Table 1 Grazing prohibition degree (GPD) and the livestock's daily fresh grass consumption (DFGC)

GDP (%)	0	10	20	30	40	50	60	70	80	90	100
DFGC (kg)	5	4.5	4	3.5	3	2.5	2	1.5	1	0.5	0

complete grazing, each sheep grazes 5 kg fresh grass per day (based on investigation). Accordingly, when a value of GPD is 10 %, each sheep would graze 4.5 kg grass per day. With the increase of GPD, the amount of grass for livestock grazing daily gradually decreased. When a value of GPD is 100 %, which is the case of full grazing prohibition, the amount of grass for livestock grazing per day is 0 kg (Table 1). Therefore, by changing GPD, the amount of grass for livestock grazing per day could be changed, and the desertification areas with the different GPD (0, 10, 20, 30, 40, 50…… 100 %) could be simulated by the System Dynamics Model.

Yanchi County's prohibiting grazing policy came into effect in November 1, 2002, and in fact, the prohibiting grazing policy turned out to be effective in 2004 because of the difficulty in implementation. The different GPD were developed into different scenarios. And then, these scenarios were input into the model to simulate, and the simulation results are shown in Fig. 5. As the value of GPD increased, the increasing trend of desertification area decreased. When the value of GPD was 30 %, desertification area began to decline, indicating that the trend of desertification turned into reversal. When the value of GPD was 40 %, desertification continued rehabilitating, but changed slightly. Then with the value of GPD continuing to increase, the decreasing trend of desertification area did not change any more, but tended to be stable, and the desertification area maintained at a certain level but decreased slightly. At the moment, the model simulated values and the actual values are so close to each other, and the relative error is only 0.3 %. Therefore, the GPD of 30 % could be the reversal threshold of grassland desertification and its rehabilitation in Yanchi County: when the value of GPD is ≥ 30 %, desertification would begin to rehabilitate, and when the value of GPD is < 30 %, desertification would continue to develop.

Effects evaluation of prohibiting grazing policy

Actually, Grazing is not completely prohibited after the implementation of prohibiting grazing policy in Yanchi County. A survey result from household showed that 67.7 % of them thought that the national implementation of prohibiting grazing policy was reasonable and would have a great effect on ecological and environmental protection. However, to some extent, the prohibiting grazing policy was undermined by the households' short-term economic interests. Thus, in the process of grazing prohibition, grazing secretly is widespread, and 70 % of households have done that (Chen and Su 2008). Nevertheless, without any significant changes in natural conditions, there is still obvious desertification rehabilitation since the implementation of prohibiting grazing policy in Yanchi County. It is because the households' secretly grazing obviously have not exceeded the reversal threshold of desertification (GPD = 30 %). Hence, it can be inferred that although the objectives of prohibiting grazing policy was not fully achieved, the policy had played a key role in desertification reversal, indeed in Yanchi County.

According to the above simulation results from the model, when the value of GPD is 40 %, the trend of desertification is stable, and then, when the value of GPD continues to increase until completely grazing prohibition, the speed of desertification reversal could not increase any more. Prohibiting grazing policy indeed played a very important role in the early stages of desertification reversal, especially in the regions with a serious desertification.

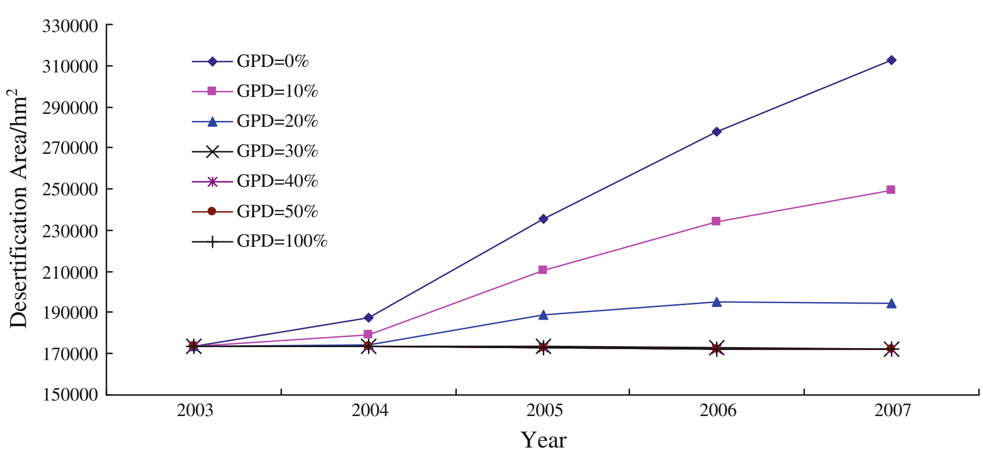


Fig. 5 The model simulation results of grazing prohibition effect of Yanchi County

However, with the higher degree of desertification reversal, prohibiting grazing policy can neither enhance the capability of grassland yield, nor reduce desertification area more effectively. Therefore, a more reasonable alternative grazing management policy is urgently needed in Yanchi County. Taking the characteristics of grassland growth and regeneration into consideration, there should be no need to implement the fully prohibiting grazing policy throughout the year. Some studies (Li 2005) indicated that moderate livestock grazing on grassland was the most reasonable economic production of pastoral farming, and moderate grazing could also stimulate the regeneration of pasture, and improve grassland productivity (Ren and Mou 1964).

Conclusions

Desertification and its rehabilitation process could be dramatically affected by ecological environment protective policies in northern China. In this paper, the system dynamics model was used to conduct the quantitative evaluation on the effect of prohibiting grazing policy on grassland desertification reversal process in Yanchi County located in northern China. The results showed that desertification extent decreased with the increase of the grazing prohibition degree. When the grazing prohibition degree (GPD) was 30 %, desertification began to rehabilitate. Thus, 30 % implementation of GPD should be the reversal threshold of desertification and its rehabilitation in Yanchi County, and the currently full prohibiting grazing policy in Yanchi County is not necessary. There is an urgent need for a more reasonable alternative grazing management policy.

According to the results of the model analysis, when the grazing prohibition degree (GPD) is 30 %, desertification begins to appear on the reversing trend. That is to say, if we reduce the amount of livestock grazing per day on 70 % of the original amount, the grassland desertification could be controlled and rehabilitated. Therefore, the implementation of rotational grazing, seasonal grazing, or direct control of the daily grazing time, amount, etc. can be used to achieve this purpose. However, this is only a preliminary theoretical study about quantitative evaluation on the effect of prohibiting grazing policy, and the results have the potential to be the most effective strategy for grassland desertification rehabilitation. More intensive studies are required to develop models of pastoral farming and promote desertification sustainable rehabilitation and local socio-economic sustainable development in Yanchi County and in other similar regions in agro-pastoral ecotone of northern China.

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